NEW OPPORTUNITIES FOR VENTILATION ASSISTANCE IN BUILDINGS UNDER SAHARAN CLIMATIC CONDITIONS

by

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Original scientific paper
https://doi.org/10.2298/TSCI151205167K

The aim of this paper is devoted to the coupling of ventilation systems with buildings with low energy performances under a specific Saharan climate. In the second part, the objective is to diagnose and quantify energy consumptions due to the ventilation of a real residential building in Ghardaia site.
As result, ventilation system can bring a positive support to the thermo-aeraulic comfort by controlling the mass flow rate of the air entering to the heated or/and cooled building zone. Heat losses due to the ventilation system represent 4.75% of the total losses; the provided heat exchange in this case requires an additional consumption of around 6.6058% of the total energy needs.

Key words: *ventilation, multi-zone model, temperature, relative humidity, mass flow rate, energy consumption, heat losses*

Introduction

Ventilation systems are types of systems which collect solar energy and transform it into heat. These systems are used to ensure a permanent heating or cooling according to the current weather period. Wang *et al* [1] justified that heating and ventilation are certainly the key parameters to ensure a pleasant thermal comfort. The incorporation of photovoltaic thermal hybrid solar collectors (hybrid PV/T) can also present efficient solutions for solar heating and thus to ensure an acceptable comfort [2]. In [3], alternative designs for the ventilation systems are considered. As result, in the presence of air leakages (unintentional openings) in the enclosure of the building, the efficiency of the dynamic insulation is significantly decreased. Some authors [4] investigated the usefulness of night ventilation technique for residential buildings in hot-humid climate. But from the field experiment, they showed that Malaysian citizens prefer daytime ventilation, although the night ventilation is the best concept. In [5] results show that passive cooling of buildings by night-time ventilation is a viable method for addressing the issue of summer overheating in the whole of northern europe, in central, eastern and even in some regions of southern Europe. In fact, under Mediterranean climates and from a thermal analysis of natural ventilated buildings, it is proven that 12% of

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the energy might be saved in one year [6]. A brief summary of the used methods is also presented with providing some tracks to characterize and evaluate the thermal performance of any solar air system. Through an extensive research, Dragićević *et al.* [7] indicated that the efficiency of the heating system by solar wall is enhanced with the increase in air velocity in the entrance duct. Huseyin [8] noted that artificial neural networks can be used for prediction of thermo-aeraulic comfort and thermal performances of solar air systems. The main criterion chosen by Givoni [9] for evaluating the performance of the buildings was the indoor maximum air temperature and its reduction below the outdoors maximum. Kolokotroni *et al.* [10] have proposed a method based on the thermal response of each room, which is modelled as network of thermal conductance and capacitance.

In this contribution, an optimized opening or a solar wall with opening can provide summer or/and winter ventilation. The significance of this work is to lift a serious problem that is often encountered in the summer when the indoor air cooling mode through natural ventilation becomes ineffective. The originality lies in the specificity of the climate region and inherent stochastic properties of weather patterns, causing commonly sensations of discomfort and therefore making it difficult to control the ventilation system. A transient thermal model, based on the heat balances of different components has been developed. Also, the proposed model is based on the thermal nodal method [11-16] which is very widespread because it requires a reduced memory capacity; allows having results in a relatively short time. In the second objective, the calculation method has as object a specific regulatory calculation of the conventional energy consumption of an existing building for heating, ventilation and cooling. The production of domestic hot water, free and internal loads related to lighting, occupants and equipment are not considered. The method refers to an integrated approach for assessing the heating and cooling energy performance of residential buildings in the Saharan climate. We are also interested in a technical and economic study to determine the corresponding energy cost.

Case study: building description and an overview of the climate in Ghardaia site

Ghardaia province (capital of the M'zab valley) is located in the center of the northern part of the Sahara desert at 32°30 north altitude and longitude 3°45. The fundamental nature of the Saharan climate is dry air, but microclimates play a considerable role in the desert with cold winter and hot summer. The annual average temperature is 22.46 °C, with 34.85 °C in July, the hottest month and 11.57 °C in January for the coldest month. This characterization is made from a synthesis climate of ten years between 2002 and 2011. The average sunshine duration was 282.60 hours per month, with a maximum of 337.30 hours in July and a minimum of 234.50 hours in December. The average sunshine duration between 2000 and 2009 was 3391.20 hours per year *i. e.* approximately 9 hours per day. The relative humidity is very low; it is of the order of 21.60% in July, reaching a maximum of 55.80% in January, and an annual average of 38.33% [17].

A typical most commonly used construction in the region had been chosen (fig. 1). The house has a surface of 95.74 m^2 with a living space of 71.3 m^2. The height of walls is 2.8 m. This building is characterized by poor compactness, exposed to outdoor conditions at all levels. Some properties are set out in tab. 1. For the window, wood blinds usually separated from the flat glass by an air-gap of 2 cm. The doors are made of wood with a thickness of 2 cm: λ = 0.14 W/mK, ρ = 500 kg/m^3, and C_p = 2500 J/kgK, (λ, ρ and, C_p are, respectively, thermal conductivity, density, and specific heat).

Table 1. Layer thickness, walls composition, and thermal transmittance *U* values for building envelope

	Exterior / Interior walls				Ground				Roof			Flat glass
Composition	Mortar cement	Stone	Mortar cement	Coating plaster	Tiling	Cement	Stone	Concrete	Plaster	Slab	Mortar	Single pane, clear
Thickness [cm]	1.5	40/15	1.5	1	2.5	1	6	24	1.5	12	3	
U [$Wm^{-2}K^{-1}$]	1.97/2.82				0.93				1.05			5.91

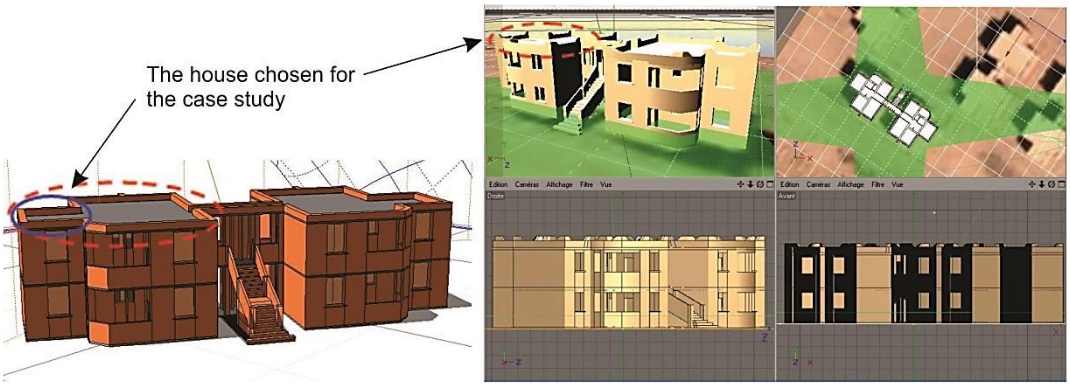

Figure 1. The 3-D building modeling

Modelling of multi-zone buildings

The scope of this work is to use a systematic approach to determine temperature and relative humidity values and their range of variability.

Methodology

In this contribution, thermal nodal method was used to apprehend thermal behavior of air subjected to varied solicitations. For an envelope's wall, we suppose that we have two temperatures as conditions to a surfaces limits. In the hypothesis of mono-dimensional conductive transfers, the studys frame is then divided into a determined number of elements supposed in each moment of a uniform temperature. The transposition of the thermal problem of conduction into an electrical problem is called thermo-electrical analogy. Therefore, the splitting up of the building into thermal zones induces the setting of nodes of temperature and relative humidity by zone. We have been induced to assign a type to each node. On the external and internal faces of the envelope's wall, the surface node is concerned with outdoor radiative and convective exchanges, this structures size being linked to the dimensions of systems to be solved.

The determination of the temperature and humidity of the air inside the room is carried out using the Runge-Kutta of order 4. The incident solar radiation on a horizontal surface and for a vertical plane facing south, north, east, and west was determined using numerical models [17]. For input climate data, we have used the polynomial interpolation technique. We require rigorous discretization of time interval, depending on the complexity of the climate variable. This method will increase the execution time of the program but it allows for more precision in calculations.

Mathematical model

For the multi-zone building modelling, temporal variations in mass are very low amounts, and the change in enthalpy can be assimilated to the variation in temperature [12-14]:

$$\rho_{as} C_{as} V(i) \frac{\mathrm{d}T_{al}(i)}{\mathrm{d}t} = \sum_{i=0}^{N} \left\{ Q_{\text{mas}}^{\text{trans}}(i,n)\, C_{as} \left[T_{al}(n) - T_{al}(i)\right] \right\} + \sum_{j=i}^{NW(i)} \left\{ S_j h_{cij} \left[T_{sij}(i) - T_{al}(i)\right] \right\} + P_s + CI_s \tag{1}$$

The second equality term of eq. (1) represents the convective flow exchanged between surfaces j of walls for zone i corresponding to a temperature, T_{sij}, and the air mass in this zone corresponding to a temperature, T_{al} [W]. Here S [m^2] is the surface, C_{as} [Jkg^{-1}K^{-1}] – the heat capacity of the air mass, t [s] – the time, $V(i)$ – the volume of zone i, ρ_{as} [kgm^{-3}] – the density of the air mass, $Q_{\text{mas}}^{\text{trans}}(i,n)$ [kgs^{-1}] – the mass flow of the dry air transiting from zone i to zone n, CI_s [W] – the internal sensitive powers due to appliances, occupants and lighting, P_s [W] – the sensitive powers provided by the air-conditioning, and h_{cij} [Wm^{-2}K^{-1}] – the convective transfer coefficients. We obtain a system of n equations with n unknowns. The main variables are the air temperatures in each zone [12-14]:

$$m_{as}(i) \frac{\mathrm{d}r_s(i)}{\mathrm{d}t} = \sum_{i=0}^{N} \left\{ Q_{\text{mas}}^{\text{trans}}(i,n) \left[r_s(n) - r_s(i)\right] \right\} + \frac{P_L}{L_v} + \frac{CI_L}{L_v} \tag{2}$$

where L_v [Jkg^{-1}] is the latent heat of vaporization of water , CI_L [W] – the internal sensitive powers due to appliances, occupants and lighting, P_L [W] – the sensitive powers provided by the air-conditioning, and r_s [kg$_{\text{vap}}$/kg$_{\text{as}}$ or %] – the specific humidity or humidity ratios; mass of water vapor contained in the unit mass of dry air. As for the sensitive balance, a system of n equations with n unknowns is obtained. The main variables are the specific humidities in each zone. Specific humidity may be expressed as a function of relative humidity by the following relationship [12-14]:

$$r_s = \frac{0.622\ P_{\text{sat}}(T)\ Hr}{101325 - P_{\text{sat}}(T)\ Hr}, \quad P_{\text{sat}}(T) = \mathrm{e}^{23.3265 - \left(\frac{3802.7}{T}\right) - \left(\frac{472.68}{T}\right)^2} \tag{3}$$

where Hr [%] is the relative humidity and P_{sat} [Pa] is the pressure of saturation vapor.

The surface temperature, T_{sij}, will be obtained by establishing thermal balance of the wall inner surface. For more clarification, consult articles given in references [11, 16]. The previous enthalpy balance gives a complete description of different phenomena inside the building. If we integrate an optimized ventilation system, there will be an additional heat-flow exchanged between the inside and outside air through the solar wall system. The sensible heat transfer rate due to ventilation is given by the following expression:

$$Q_{\text{vent}\_S} = \eta_{\text{air}\_sws}\ c_{\text{air}\_sws} \left(T_{\text{air}\_sws} - T_{al}\right) \tag{4}$$

In the same way, the latent heat transfer rate due to ventilation is given by eq. (5):

$$Q_{\text{vent}\_L} = \eta_{\text{air}\_sws}\ L_{\text{vap}} \left(r_{\text{air}\_sws} - r_{al}\right) \tag{5}$$

We can calculate comfort parameters by adding the expression 4 to the second term in eq. (1) and expression 5 to the second term in eq. (2).

Ventilation effect: results and discussion

During the design phase, an appropriate temperature difference to use for estimating ventilation would need to be derived from climate and building load data. It is essential to equip houses with a ventilation system adapted to the living space and to different rooms.

In winter, the outside fresh air can supply during the day areas to be heated. The application below is an example which illustrates the reach level of the thermo-aeraulic comfort. The measured temperatures of the outside air are between 9.03 and 25.01 °C (fig. 2), external ambient relative humidity corresponds to values less than 46% and greater than 32% (fig. 3), the sky is completely clear. The behavior of the wind speed is completely random (fig. 4). The determination of the temperature and humidity of the air inside the room surrounded by the blue color is carried out using the Runge-Kutta of order 4. According to the results given in fig. 2, the relative algebraic error is less than 7.97% for the air temperature. The minimum relative error is 0.13% and its average value equal to 3.17%. The average difference in temperature equal to 0.5609 °C, the absolute error varies between 0.0211 °C and 1.3548 °C.

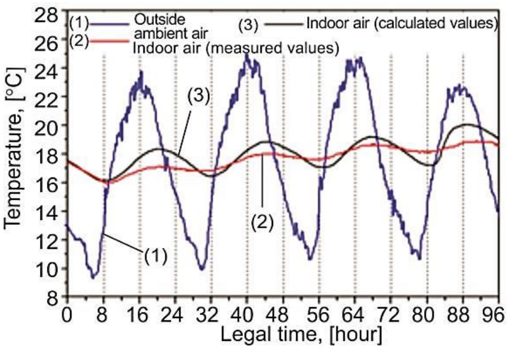

Figure 2. Ambient and air temperatures in the room

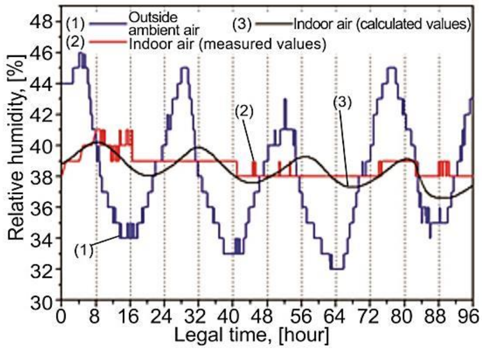

Figure 3. Relative humidity of the ambient and indoor air

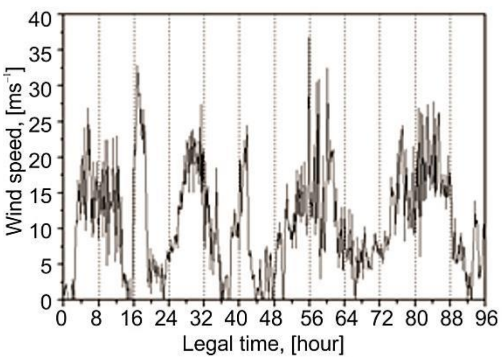

Figure 4. Wind speed profile

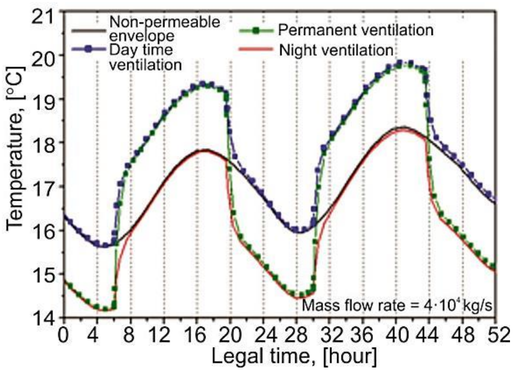

Figure 5. Ambient and air temperature in the room

However, in fig. 4 indicative curves representing the relative humidity profiles designate that the mean relative algebraic error, minimum and maximum relative error committed are respectively 1.62%, 0.03%, and 6.14%. The average difference in relative humidity equal to 0.63%, the absolute error ranges from 0.01% to 2.39%. Following this study, the comparison between the measured and the computed values is acceptable.

As far as I know, there are no available adequate research works which deal and completely regulate the ventilation concept for all possible situations. This is mainly linked to the special nature of this climate. In addition, in the presented results, we have taken types and ventilation scenarios into consideration according to the extreme temperature variations of the outdoor air. Figure 5 shows an effective application for the ventilation application following the approach adopted in the mathematical model. According to this figure and unlike night-time, outside temperatures are often higher than that of the interior during the daytime period (fig 2). In these situations, daytime ventilation provides the best compromise of thermal comfort. In the absence of solar radiation and during the night-time, the flow direction of the air causes an accelerated cooling of building. Permanent ventilation leads to a heat loss during the night-time because the warm air is discharged directly into the outside whereas the outside cold air-flow must be reheated. In what follows, however, we generalize our result (even if they are not presented) for all the remaining periods in the year, considering different circumstances encountered. We compare thermal conditions between daytime ventilation and night ventilation and examine cooling and heating effect between night and full-day ventilation.

The summer intensive ventilation can cool a building by ventilation system using the free energy of the external air when this one presents a lower temperature than that of the indoor temperature. In Ghardaia, the mean monthly maximum values of temperatures for the year 2012 amounted to 28.80, 33.48, 38.77, 42.34, 41.32, 35.95, and 30.48 °C from April until October, respectively. At night, the mean monthly minimum values of temperatures for the year 2012 are estimated respectively at 14.12, 19.43, 22.91, 27.19, 26.76, 21.22, and 16.51 °C ranging from April to October [18]. For the months of April, May, June, September, and October, we can enjoy the phenomenon of thermal draft because on the one hand temperatures of the indoor air is greater than that of the outer and on the other the difference between the minimum and maximum temperatures is acceptable to create a pressure difference and therefore a controlled circulation of air.

On top of that night, time is sufficiently cool. Night ventilation can unload the accumulated daytime heat in the building, the principle is to cool the thermal mass at the night time. This cooling allows preserving the night freshness and then restoring it during the day to minimize the overheating or to decrease the cooling needs. The advantage of this strategy is to refresh the interior air even when daytime temperatures are relatively high in the case of a decreased of the night outside temperature. Unfortunately, this condition is often absent for the months of July and August for the Ghardaia site.

During the daytime ventilation, if the outside air is cooler than the inside air, ventilation generates heat loss by renewable air and therefore an evacuation of a part of internal and solar gains. In the case where the outdoor temperature is greater than the internal, daytime ventilation can not be used for cooling as the case in Ghardaia climate for most of the summer. In the warm period, night-time ventilation might not be sufficient to guarantee thermal comfort due to warmer nights that can occur and the inherent stochastic properties of weather patterns.

In summary, after a depth analysis of the climatic conditions, we find that:

– for the months of July and August, the heat exchange by ventilation system is not used to cool the ambient temperature regardless of the type of ventilation (continuous, nocturnal or diurnal). Under these conditions, ventilation allows only to renew the interior air.
– for the months of June, September, and October, night ventilation can sometimes bring lower indoor temperatures when the outside temperature is lower compared to those of the interior,
– in addition to improving the indoor air quality, daytime ventilation can generally provide satisfactory heating for a period running from September until March, and
– all these results were confirmed by the application of our simulation tool based on the proposed model and taking into account the outside air temperature, the measured and calculated temperature inside the building. We performed the same steps that were followed in the previous example.

Diagnosis and quantification of energy needs due to the ventilation system

In this section we aim to present results of total annual building energy consumptions. Energy needs expressed in W/K are calculated:

$$Q_{\text{needs}} = DP_{\text{envelop}}\,(1-F) \tag{6}$$

where F is the fraction of the heating needs covered by free gains (solar and internal gains).

In the absence of free gains (F = 0), needs in heating and cooling calculated for a building per degree of temperature difference between the inside and outside, expressed in kWh are given by:

$$C = 24\,Q_{\text{needs}}\,Dj = 24\,DP_{\text{envelop}}\,Dj \tag{7}$$

where DP_{envelop} [WK^{-1}] is the sum of heat loss through ventilation and all building components and Dj is the heating and cooling degree days. Degree days are a specialist type of weather data, calculated from readings of outside air temperature. Heating degree days and cooling degree days are used extensively in calculations relating to building energy consumption. The input data are heat transfer coefficient, U [Wm^{-2}K^{-1}] and wall surfaces, S_i [m^2]:

$$DP_{\text{envelop}} = DP_{\text{ceilings}} + DP_{\text{walls}} + DP_{\text{windows}} + DP_{\text{doors}} + DP_{\text{floors}} + DP_{\text{thermal\_ridges}} + DP_{\text{ventilation}} \tag{8}$$

The calculation of heat loss for each term is made from the following equations:

$$DP_{\text{ceilings}} = \sum_{i=1}^{i=n} b_{\text{ceilings\_i}}\,S_{\text{ceilings\_i}}\,U_{\text{ceilings\_i}} \tag{9}$$

$$DP_{\text{walls}} = \sum_{i=1}^{i=n} b_{\text{walls\_i}}\,S_{\text{walls\_i}}\,U_{\text{walls\_i}} \tag{10}$$

$$DP_{\text{window}} = \sum_{i=1}^{i=n} b_{\text{window\_i}}\,S_{\text{window\_i}}\,U_{\text{window\_i}} \tag{11}$$

$$DP_{\text{doors}} = \sum_{i=1}^{i=n} b_{\text{doors\_i}} S_{\text{doors\_i}} U_{\text{doors\_i}} \tag{12}$$

$$DP_{\text{floors}} = \sum_{i=1}^{i=n} b_{\text{floors\_i}} S_{\text{floors\_i}} U_{\text{floors\_i}} \tag{13}$$

where S_{i} [m^2] is the loss surface, b_{i} – the heat losses reduction coefficient, and U_i [Wm^{-2}K^{-1}] – the surface heat transmission coefficient per degree of difference between the inside and outside.

For the calculation of the heat losses reduction coefficient, we must consider:

– the wall surfaces separating the unheated space from the heated zone, A_{iu} [m²],
– the wall surfaces separating the unheated area from the outside, the floor or other unheated space, A_{ue} [m²],
– the type of unheated space,
– the insulation state of the adjacent walls to the unheated space, and
– the insulation state of the unheated space.

For a wall in contact with the outside, b = 1, and for a buried wall or a floor on the craw space, b = 0.8. The values of the heat losses reduction coefficient should be given in tables provided in [19] according to the area ratio A_{iu}/A_{ue} and the equivalent coefficient, U.

For the calculation of heat loss through thermal bridges, we use:

$$\begin{aligned} DP_{\text{thermal\_ridges}} = {} & \sum_{i,j} b_{pb\_\text{i}/m\_\text{j}} k_{pb\_\text{i}/m\_\text{j}} l_{pb\_\text{i}/m\_\text{j}} + \sum_{i,j} b_{pi\_\text{i}/m\_\text{j}} k_{pi\_\text{i}/m\_\text{j}} l_{pi\_\text{i}/m\_\text{j}} + \\ & + \sum_{i,j} b_{ph\_\text{i}/m\_\text{j}} k_{ph\_\text{i}/m\_\text{j}} l_{ph\_\text{i}/m\_\text{j}} + \sum_{i,j} b_{rf\_\text{i}/m\_\text{j}} k_{rf\_\text{i}/m\_\text{j}} l_{rf\_\text{i}/m\_\text{j}} + \\ & + \sum_{i,j} b_{\text{men\_i}/m\_\text{j}} k_{\text{men\_i}/m\_\text{j}} l_{\text{men\_i}/m\_\text{j}} \end{aligned} \tag{14}$$

where

– l_{pb_i/m_j} is the length of the thermal bridge, low floor i, wall j,
– l_{pi_i/m_j} is the length of the thermal bridge, intermediate floor i, wall j,
– l_{ph_i/m_j} is the length of the thermal bridge, top floor i, wall j,
– l_{rf_i/m_j} is the length of the thermal bridge, shear wall i, wall j; l_{rf_i/m_i} = 2 hsp (N-n_{iv}) with hsp – the average ceiling height, N – the number of apartments, and n_{iv} – the number of levels, and
– l_{men_i/m_j} is the length of the thermal bridge, shear wall i - wall j, l_{rf_i/m_i} = 2 hsp (N-n_{iv}) with hsp – the average ceiling height, N – the number of apartments, and n_{iv} – the number of levels.

For our application case, the proposed apartment is of low compactness and poorly insulated, the dominant thermal bridges correspond to the fourth type, l_{rf_i/m_i} = 0.73 m.

The k [Wm^{-1}K^{-1}] is the value of the equivalent thermal conductivity of the thermal bridge, it is a parameter which depends both on the type of insulation and its link type (as the length of the thermal bridge). The retained values are given in detail in reference [19].

To calculate the heat loss by air exchange, it must be based on the following input data: carpentry (with or without joint), surface of deperditive wall excluding low-floor, living area and ventilation type [19, 20]:

$$DP_{\text{ventilation}} = DP_{\text{vent}} + DP_{\text{perm}} \tag{15}$$

where $D\text{P}_{\text{vent}}$ [WK^{-1}] is the heat loss through the air changes due to the ventilation system per degree in temperature difference between the inside and outside and DP_{perm} [WK^{-1}] is the heat loss through the air changes due to the air permeability of the building per degree in temperature difference between the inside and outside.

$$DP_{\text{vent}} = 0.34\ \theta_{\text{conv}} S_h \tag{16}$$

where θ_{conv} [m^{3}h^{-1}m^{-2}] is the conventional extract air-flow per unit of living space and S_h [m²] is the living area.

$$DP_{\text{perm}} = 0.34\ \eta_{\text{inf}} \tag{17}$$

where η_{inf} [m^{3}h^{-1}] is the air-flow due to infiltration caused by thermal draft phenomena [19, 20].

$$\eta_{\text{inf}} = 0.0146\ \eta_{4pa} \left(0.7|19 - Tex_{\text{mean}}| \right)^{0.667} \tag{18}$$

where Tex_{mean} [°C] is the mean value of outside temperature.

$$\eta_{4pa} = \eta_{4pa\_\text{env}} + 0.45\ Sme_{\text{conv}} S_h \tag{19}$$

where $\eta_{4\text{pa}}$ [m^{3}h^{-1}] is the permeability under 4 Pa of the zone, $\eta_{4\text{pa\_env}}$ [m^{3}h^{-1}] is the permeability of the envelope, and Sme_{conv} [m^{3}h^{-1}m^{-2}] is the conventional value of the sum of the inlet air modules under 20 Pa per unit of living surface.

$$\eta_{4pa\_\text{env}} = \eta_{4pa\_\text{env/m}^2}\ S_{dep} \tag{20}$$

where $\eta_{4\text{pa\_env/m}^2}$ [m^{3}h^{-1}] is the conventional value of permeability under 4 Pa and S_{dep} [m^2] deperditive surface excluding low-floor.

For a window without joint $\eta_{4\text{pa\_env/m}^2}$ 2.5 m^{3}h^{-1}, for other cases, it is equal to 1.7 m^3 per hour. In case of air exchange, we assume that the ventilation system is made in the high and low inlet openings, the corresponding values of Sme_{conv} and θ_{conv} are, respectively, 4 and 21450 [19, 20].

The next section is devoted to calculate the annual heating and cooling requirements for the indicated house in fig. 1. The first case concerns the study of a perfectly tight house, unlike the first and in the second case, the house is permeable to the air (ventilation). In this study, respiration and the human radiation, appliances and multimedia are also potential sources of energy supply that will not be considered. The estimated consumption is based on energy costs and readings of energy counters. Before any study and to quantify the major energy losses, we seek the percentage of heat loss of each element to properly target the greatest heat loss in this housing, this is announced in fig. 6. Calculations certify that the roof, exterior walls and floor are the main sources of heat losses. On average, they include 81.81% of total losses. Consequently, we judged that the optimal way to reduce energetic consumption is to enhance the external thermal insulation in building envelope. We proved by this same study that heat losses due to the ventilation exchange represent around 4.75% of the total losses.

Table 2 summarizes the monthly heating and cooling requirements during 2014. This energy demand used to secure a permanent cooling for all areas of the house during these months considering that 23.5 °C is the desired temperature. We are also interested in a tech-

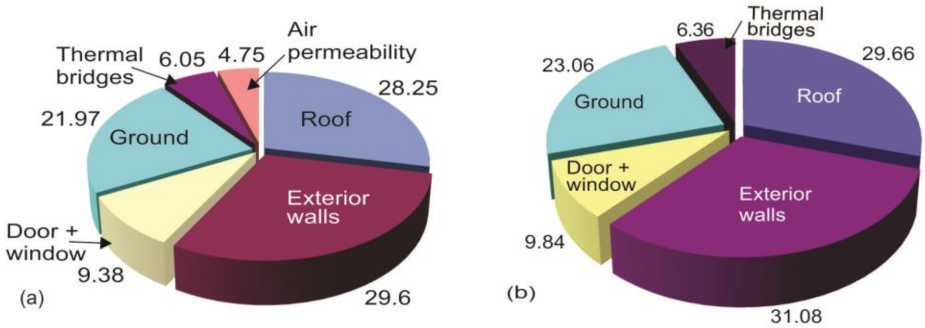

Figure 6. Energy assessment of this real single-family house (by percentage of total losses); (a) permeable house to the air, (b) perfectly tight house

nical and economic study to determine the corresponding energy cost. The calculation procedure of the relative cost per quarter is adopted in accordance with the used method of Algerian state (SONELGAZ). The SONELGAZ is a public company, responsible for the production, transportation, distribution and marketing of electricity and gas in Algeria. For consumption below 125 kWh, the unit cost is 1.779 DA (0.0169 EUR), beyond this threshold, *i. e*. for consumption greater than 125 kWh the price will become 4.179 DA (0.0396 EUR) per kWh. The final price takes into account taxes and state subventions (50% regardless of taxes).

Figure 7 formally combines the predicted values given in tab. 2 to maintain the desired comfort in terms of temperature. Four situations are to be analyzed of a multi-zone home with and without inclusion of this architectural technique for two different cases without and with air exchange.

Building heating extends from November to April, whereas annual heating needs are significant, representing about 51.53% of the annual heating and cooling needs for the year of 2014. According to statistics, air ventilation system causes an average increase in energy consumption of about 6.61%. We note that the increase in energy consumption due to the ventilation reached record values during the summer months especially July and August. By finding, annual energy consumption relative to the heating and cooling requirements which keeps temperature at 23.5 °C in all areas of this type of an airtight house (including the kitchen, bathroom, toilet and hall) during all year without any rupture is estimated at 33357.03 kWh per year. However, in accordance with the retained temperature, the financial estimate for the entire habitable volume and is estimated at 2144247 DA per year, which is equivalent to 20325 Euro per year.

In Algeria, the periodic quarterly payment of electricity bills is the imposed procedure. That is why we give results for a period of three months to have a valuable idea and to make them comparative with the real modalities of our lifestyle. If we limit our comfort perimeter only to the living room (3.6 m × 3 m × 2.8 m), and through an analysis on the total cost of the energy consumption which maintains a constant temperature of 23.5 °C in the third quarter (July, August, and September) of 2014 for example, we must invest an amount of 4053.70224 DA (38.4237 Euro). Now, if we want to maintain this internal temperature during all the year, this requires an investment corresponding to an amount of 11227.0899 DA (106.4179 Euro). As unprecedented information, we reiterate that Algerian state policy to support people in the South induced a reduction of 50% in electric energy consumption. It is for this reason that the unit price of the electric energy consumption is cheaper compared to

Table 2. Required building energy consumption to ensure a continuous cooling/heating (2014)

Month	Average outdoor temperature, [°C]	Heating/cooling degree days *Dj*	Without air exchange		With air exchange	
			C [kWh]	Cost [DA/m^3]	*C* [kWh]	Cost [DA/m^3]
January	12.3759	+344.8458	4245.0	47.1021	4539.2	50.3474
February	14.5426	+250.8083	3087.4	34.3325	3290.3	36.5707
March	15.9024	+235.5250	2899.2	32.2565	3082.3	34.2763
April	22.8701	+18.8958	232.60	2.8411	247.64	3.0070
May	26.7517	-100.8042	1240.9	13.9637	1329.0	14.9355
June	30.0394	-196.1833	2415.0	26.9152	2597.6	28.9295
July	35.4050	-369.0542	4543.0	50.3893	4916.4	54.5083
August	35.5738	-374.2875	4607.4	51.0997	4987.0	55.2871
September	31.4257	-237.7708	2926.9	32.5620	3153.4	35.0606
October	24.6431	-35.4375	436.23	5.0874	465.78	5.4133
November	17.7081	+173.7583	2138.9	23.8696	2265.2	25.2628
December	11.4862	+372.4292	4584.5	50.8471	4908.5	54.4211

the electricity bill cost in the majority countries of the world. This bill is very high and weighs heavily on the state budget, which is why we judged that an efficient integration of some passive solar constructive solutions appears as a mandatory process.

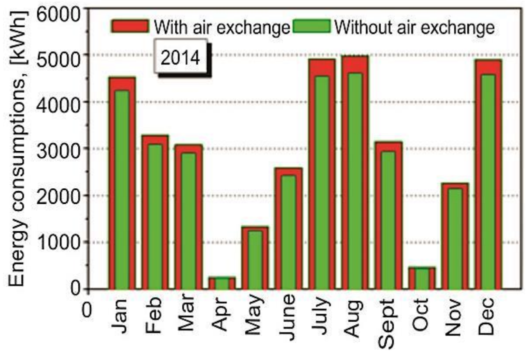

Figure 7. Monthly energy needs for space heating and cooling

Conclusions

In this study we confirmed that under a Saharan climate, an active heating/cooling system using ventilation system can increase the thermal comfort. The major inconvenience of the ventilation system is often encountered in summer season when exterior temperatures are higher than interior temperatures during all the day. We recommend the application of night-time cooling where comfortable indoor conditions cannot be achieved by daytime ventilation and where night-time temperatures are less than the maximum required (about 23 °C). The problem is also posed in the opposite case in winter season. Under these conditions, ventilation systems only serve to maintain the quality of the indoor air. In this contribution, the outside ambient air is considered as a main source of the entering air in the area, so in some cases temperatures will not be favorable to provide a sufficient heating or cooling of the indoor air. We think in these circumstances to involve the Canadian/Provençal as well.

Mechanical night ventilation would result in increased energy consumption. We must carefully consider two contradictory elements, ventilation and energy saving, heat exchange due to the ventilation requires an additional consumption of around 6.6058%. Heat losses due to this exchange type represent 4.75% of the total losses. Judicious use of ventilation systems during hot, cold and extreme weather conditions can reduce energy costs but it is not sufficient. It will combine several bioclimatic concepts in to further improve thermal comfort.

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Paper submitted: December 5, 2015
Paper revised: June 3, 2016
Paper accepted: June 6, 2016